

The Rotation of Binary Systems with Evolved Components

J. R. De Medeiros (renan@dfte.ufrn.br), J. R. P. Da Silva (ronaldo@dfte.ufrn.br) and M. R. G. Maia (mrgm@dfte.ufrn.br)

*Departamento de Física, Universidade Federal do Rio Grande do Norte, 59072-970, Natal
– RN, Brazil*

ABSTRACT

In the present study we analyze the behavior of the rotational velocity, $v \sin i$, for a large sample of 134 spectroscopic binary systems with a giant star component of luminosity class III, along the spectral region from middle F to middle K. The distribution of $v \sin i$ as a function of color index ($B - V$) seems to follow the same behavior as their single counterparts, with a sudden decline around G0III. Blueward of this spectral type, namely for binary systems with a giant F-type component, one sees a trend for a large spread in the rotational velocities, from a few km s^{-1} to at least 40 km s^{-1} . Along the G and K spectral regions there is a considerable number of binary systems with moderate to moderately high rotation rates. This reflects the effects of synchronization between rotation and orbital motions. These rotators have orbital periods shorter than about 250 days and circular or nearly circular orbits. Except for these synchronized systems, the large majority of binary systems with a giant component of spectral type later than G0III are composed of slow rotators.

Subject headings: binaries: spectroscopic, stars: fundamental parameters, stars: late-type, stars: rotation

1. Introduction

Rotation is one of the most important observable physical parameters in stellar astrophysics. Such a parameter can provide fundamental constraints for models of stellar evolution, as well as important information on the link between surface rotation and stellar atmospheric phenomena. The behavior of the rotational velocity for single evolved stars of luminosity class III is now well established (De Medeiros and Mayor, 1989, 1991; Gray, 1989). For this luminosity class, there is a sudden decline in the rotational velocity around the spectral type G0III, which corresponds to $(B - V) \sim 0.70$. Blueward of this spectral type,

namely for F type single giants, rotational velocity scatters over a wide range of values, from about 2 to 180 km s⁻¹, whereas redward, namely for G and K-type single giants, stars are essentially slow rotators and rotation rates greater than 5 km s⁻¹ are unusual. On the basis of the analysis of kinematic–age relation, De Medeiros and Mayor (1991) have shown that the root cause for this discontinuity in rotation seems to be a mixing in ages associated with the rapid evolution of giant stars into the Hertzsprung Gap. These observational results have been discovered from a large rotational and radial-velocity survey of about 1100 giants (De Medeiros and Mayor 1999) accomplished with the CORAVEL high-resolution spectrometer (Baranne et al. 1979) at the Haute Provence Observatory, in France, and at the European Southern Observatory in Chile.

We have now examined the complete survey for the spectroscopic binary systems containing a giant component of luminosity class III. The main challenge in the study of rotation in binary systems with evolved components is to establish the extent of the synchronization between rotational and orbital motion along the giant branch. Tidal theory (e.g., Zahn 1977) predicts that, in late type binary systems, viscous dissipation of time dependent tidal effects should produce synchronization between rotation and stellar orbital motion, as well as circularization of the orbit of the system. The most simple way to test such effects consists of the determination of precise rotational velocities for a large sample of binary systems with giant components, presenting a wide variety of values of orbital parameters. On the basis of tidal predictions, Middelkoop and Zwaan (1981) have suggested that most late type giants in close binary systems, with orbital periods shorter than about 80 days, rotate in synchronization with revolution, because most of these close binary systems have circular orbits. Such a tendency for synchronization in late type binary systems was also observed by Giuricin et al. (1984). Mermilliod and Mayor (1992) have found that, in open clusters, binaries containing a giant have circularized orbits at orbital periods shorter than about 250 days. More recently, Boffin et al. (1993) have deduced a circularization cut off period of about 70 days from an eccentricity–period diagram for a large sample of field binary systems containing late type giants.

In the present work, we study the behavior of the rotational velocity $v \sin i$ as a function of the color index ($B - V$), for a large sample of binary systems with a giant component of luminosity class III. We also analyze the link between $v \sin i$ and the orbital parameters eccentricity and orbital period.

2. The observational data

The entire sample for the present work is composed of 134 single lined spectroscopic binary systems, SB1, with spectral types between F5III and K5III, mostly from the Bright Star Catalogue (Hoffleit and Jaschek 1982; Hoffleit et al. 1983), including 73 binaries for which the orbits are known from the literature. Observations were carried out with the CORAVEL spectrometer (Baranne et al. 1979) mounted on the 1.0 m Swiss telescope at the Haute Provence Observatory, France, and on the 1.44 m Danish telescope at the European Southern Observatory, Chile, between March 1986 and January 1994. For the determination of the projected rotational velocity $v \sin i$, we have applied a standard calibration (Duquennoy et al. 1991; De Medeiros and Mayor 1999) which takes into account a varying broadening mechanism, as a function of color, probably related to turbulent motions and/or magnetic fields. Nevertheless, let us recall that such calibration is an extension of the method developed by Benz and Mayor (1981, 1984) which is based on the cross correlation technique (Griffin 1967). For the observational procedure, calibration process and error analysis, the reader is referred to De Medeiros and Mayor (1999). A comparison of our measurements, obtained by the cross correlation technique, with those acquired with the Fourier–transform technique by Gray (1989) for a common sample of 84 single and binary giant and subgiant stars, gives excellent agreement, with a typical rms of the rotational velocity differences of about 1.1 km s^{-1} , indicating a precision of 1.0 km s^{-1} for our $v \sin i$ measurements (De Medeiros and Mayor 1999). This excellent agreement between the $v \sin i$ values from CORAVEL and Fourier transform is confirmed for the binary stars, when they are analyzed separately. By using the $v \sin i$ data given in Table 1 for 15 stars of the present sample, we have found a rms of the rotational velocity differences of 0.61 km s^{-1} .

The entire sample for the present work, with rotational velocity and orbital parameters, when the latter are available, is listed in Table 3. For those stars with no available orbital parameters Table 3 gives also for each star, the number N of observations; the radial velocity dispersion (rms) σ ; the uncertainty ϵ on the mean radial velocity, given by $\max(\epsilon_1/\sqrt{N}, \sigma/\sqrt{N})$, where ϵ_1 is the typical error for one single radial velocity measurement; the time span ΔT of the observations and the σ/σ_n , a factor indicating how many times their radial velocity dispersion (rms) exceeds the radial velocity noise expected for single stars.

For the stars with no orbital parameters listed in Table 3, one important question concerns the nature of their radial velocity variation. Is such a variability reflecting the presence of a dynamical companion, or is intrinsic to the star, reflecting either rotational modulation by surface features or nonradial pulsations? In this context, different studies (e.g. Hatzes and Cochran 1993; Frink et al. 2001) have revealed intrinsic radial velocity variability in K

giant stars with amplitudes ranging from 0.2 to 0.4 km s⁻¹. Using the Maximum Likelihood approach we have analyzed the behavior of the factor σ/σ_n defined above, to estimate if the radial velocity variability of such stars is likely indicating a dynamical companion. For this, we have estimated the expected radial velocity noise σ for single giants, from intrinsic contributions with typical amplitude of 0.4 km s⁻¹. This amplitude value was added in quadrature with the 0.3 km s⁻¹, the typical precision of a single radial velocity measurement by CORAVEL (see Duquennoy et al. 1991), giving a radial velocity noise σ_n of 0.50 km s⁻¹. With this expected value of σ_n in hand, we have obtained the factor σ/σ_n listed in Table 3. Afterwards, we have estimated the σ/σ_n for a sample of 641 G and K single giant stars from De Medeiros and Mayor (1999). The distributions of the factor σ/σ_n for single giants and for the stars with no orbital parameters in Table 3 are displayed in Fig. 1, both very well fitted by a gaussian function. For a best presentation of the distributions, the σ/σ_n values in Fig. 1 were normalized by the highest σ/σ_n for each group of stars, namely 1.9 and 35.84 for single giants and for the stars with no orbital parameters, respectively. In addition, the frequency of single stars was reduced by a factor 5. From the Maximum Likelihood statistics we obtained a $\langle \sigma/\sigma_n \rangle$ of 0.33 ± 0.36 and 6.32 ± 4.67 for single giants and for the stars with no orbital parameters in Table 3, respectively. From this analysis we estimate that the threshold to indicate a dynamical companion is around a σ/σ_n of 0.69. Stars with no orbital parameters listed in Table 3 present a σ/σ_n higher than such threshold value, indicating that their radial velocity variabilities reflect very probably a binarity behavior.

It is important to underline that in this paper we are analyzing only the binary systems presenting a SB1 behavior on the basis of our CORAVEL observations. Double lined systems, SB2, and binaries presenting a composite spectrum will be discussed in a forthcoming work. We have excluded from the sample all those systems classified in the literature with a composite spectrum, in spite of the fact that, for some systems, the CORAVEL observations have shown a SB1 behavior.

3. Results and Discussion

The main results of the present work are displayed in Figures 2a,b and 3, where we show the distribution of the rotational velocities as a function of the color index ($B-V$) and orbital parameters. Several important features are well marked.

Figure 2a shows the general trend of the distribution of the rotational velocity $v \sin i$ as a function of the color index ($B-V$) for spectroscopic binary systems with evolved component, with a tendency for a sudden decline around $(B-V) \sim 0.70$, corresponding to the spectral type G0III. This behavior seems to follow that of the rotational velocity presented by their

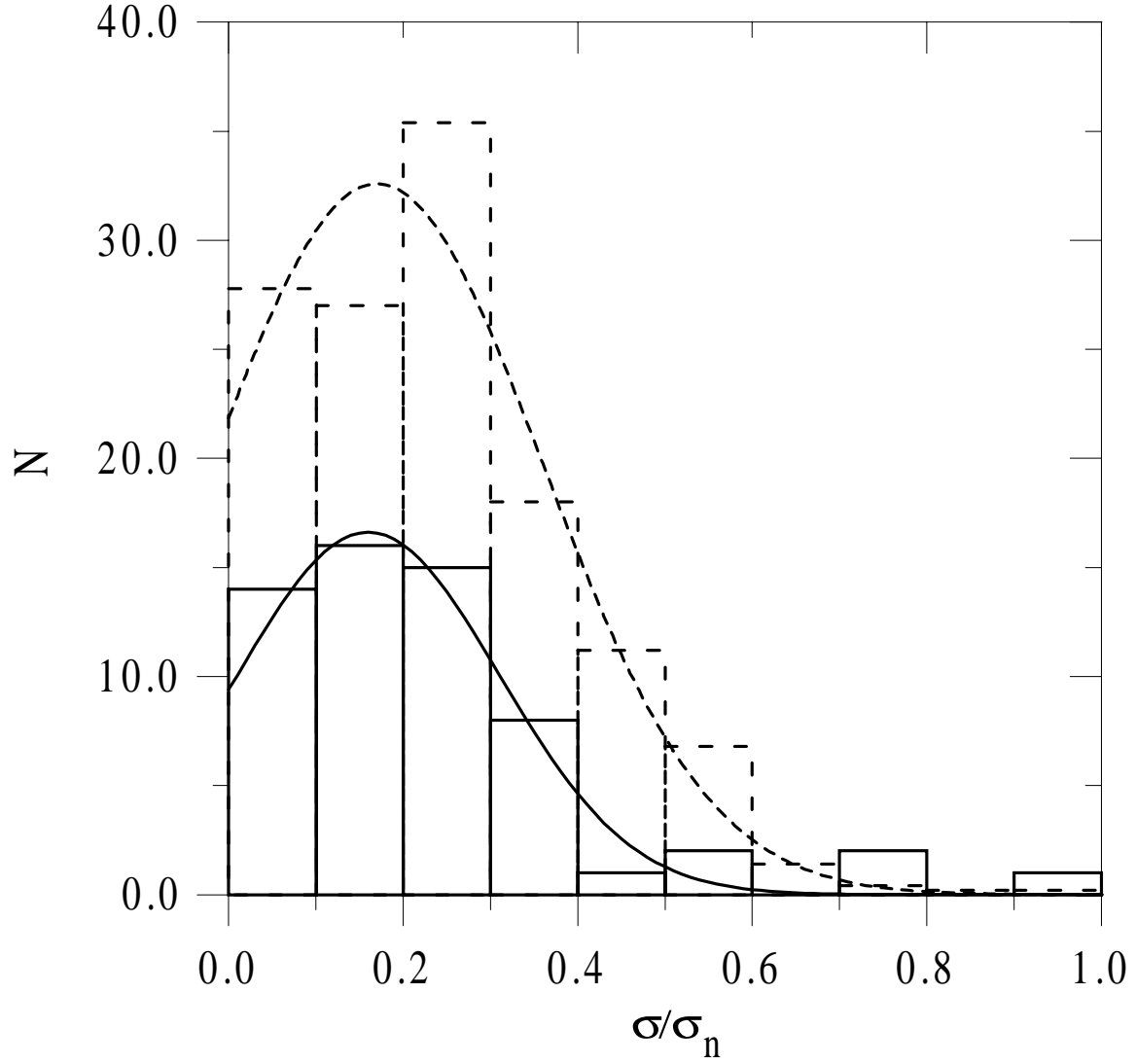


Fig. 1.— The distribution of the factor σ/σ_n for single giants stars (dashed line) and for the binary systems with no orbital parameters (solid line). For a best presentation of the distributions, σ/σ_n values and the number of single giants were normalized as explained in the text.

single counterparts. Blueward of the spectral type G0III there is a spread in the values of rotational velocity, ranging from a few km s^{-1} to at least 40 km s^{-1} , whereas redward of this spectral type, namely along the G and K spectral regions, the great majority of binary systems rotate very slowly, following the same trend observed for single giants. Let us recall that the mean rotational velocity $v \sin i$ for single G and K type giants ranges typically from about 6 km s^{-1} at G1III, to about 3 km s^{-1} at G5III and to about 2 km s^{-1} along the spectral region from G8III to K7III (De Medeiros et al. 1996). Nevertheless, twelve out of 124 binary systems located redward of G0III showing moderate to moderately high rotation rates, typically stars with $v \sin i$ higher than 6 km s^{-1} . For a more consistent analysis on the extent of the decline in $v \sin i$ shown in Figure 2a, one should inquire about the root cause of the enhanced rotation presented by such binary systems. By analyzing the orbital parameters given in Table 3, we find that the G and K binary systems with enhanced rotation have an orbital period shorter than about 250 days and a circular or nearly circular orbit, such a value pointing for the critical period of synchronization between axial rotational motion and orbital revolution due to tidal effects. The critical period of synchronization around 250 days found on the basis of a large sample of field binary systems, sounds an interesting result because it follows that found by Mermilliod and Mayor (1992) from a sample of 88 binary systems with an evolved component in open clusters. In this context, one can conclude that the enhanced rotation of binary systems along the G and K spectral regions results from the synchronization between rotation and orbital motions. Hence, the moderate to moderately high rotation shown by these synchronized binary systems reflects angular momentum that has been drawn from the orbital motion. The orbit acts as a source of angular momentum to replace that lost via stellar wind, during the evolution along the giant branch. It is clear that for some systems the synchronization may increase their observed rotational velocity by more than about 15 times the mean rotational velocity observed for single giant stars at a given spectral type. Following Zahn (1966, 1977), in binary stars possessing a convective envelope, tidal effects become important if the convective region occupies a substantial fraction of the star, and if convection transports most of the energy flux. According the tidal theory, in the components of a late type binary system, the tidal wave, which is due to the gravitational interaction, is slightly lagging because a small fraction of its kinetic energy is converted into heat, as required by the second principle of thermodynamics. The system evolves towards its state of minimum kinetic energy, in which the orbit is circular, the spin axes are aligned and perpendicular to the orbital plane and the rotation of both stars of the system is synchronized with the orbital motion. Such synchronism is predicted to be completed before orbits become circular (Zahn 1977), unless the spin angular momentum is comparable to the orbital angular momentum (Zahn 1977, Hut 1980). Since evolutionary models predict that the rapid increase of the thickness of the convective envelope coincides with the late F spectral region (e.g., Maeder and Meynet 1994), our finding presents strong evidence that the synchronization is

achieved once stars arrive in the late F to early G spectral regions.

At this point one should ask about the nature and the extent of the decline in rotation around G0III, suggested by Figure 2a. Is it really paralleling the rotational discontinuity at G0III observed in single giant stars? In fact we see two possible regimes. First, the synchronization is achieved only for stars along the G to K spectral regions (let us recall that the extent of the convective envelope and the effectiveness of convection in transporting energy flux become important only when the star evolves up the giant branch). In this context we can consider that binary systems in the F spectral region, in particular those with early to middle F-type component, are not synchronized, their rotation reflecting only the normal evolution of the star with no effects from binarity. Following this scenario, in Figure 2b we represent the rotational velocity $v \sin i$ as a function of the color index $(B-V)$ for binary systems with G- or K-type component, but for orbital periods longer than 250 days and all systems with an F-type component. We have also excluded from this figure the G and K binary systems with significant enhanced rotation in respect to the mean, HR 2054, HR 2145 and HR 2376, for which no orbital parameters are available in the literature, but their large radial velocity range, respectively 9.58 km s^{-1} , 10.59 km s^{-1} , and 19.19 km s^{-1} , indicates for short or moderately short orbital periods. The sudden decline in $v \sin i$ around $(B-V) = 0.70$ is now quite clear. Of course, low rotator binary systems situated along the G and K spectral regions should be mostly nonsynchronized systems. Consequently, they should have orbital periods longer than the cut-off period of about 250 days and rather non circular orbits. Nevertheless, a few systems in Table 3, like HR 373 and HR 503, have nearly circular orbits with periods shorter than 250 days and low rotation. Perhaps their true rotation rates are high but $v \sin i$ is suppressed by low inclination of their rotation axis. Second, the F-type stars with short orbital period like HR 765, and HR 2264 would have also reached a stage where convective envelope is sufficiently developed for synchronization, in spite of their middle-F spectral types. Following such a scenario we can also ask about the nature of the additional F-type stars represented in Figure 2b but with no orbital parameters available in the literature. If these stars are also in synchronization there is no supporting evidence for a rotational discontinuity in binary systems following that observed for single giants, as proposed in the first scenario above discussed. To decide between these two scenarios it is necessary, first, to determine orbital parameters for all the F-type stars composing the present sample and, second, to determine the rotational velocity for a larger number of F-type stars.

In Figure 3 we show the behavior of the rotational velocity as a function of the orbital period. Stars are separated in two groups: those with circular or nearly circular orbits, namely an eccentricity e lower than about 0.10, and those with non circular orbits, namely an eccentricity e higher than 0.10. This figure shows clearly that the binary systems with en-

hanced rotation, typically $v \sin i$ greater than about 6 km s^{-1} , have an orbital period shorter than about 250 days and circular or nearly circular orbit. Two additional trends are clearly observed in this figure: first, high rotators with orbital period longer than 250 days seems to be unusual and second, there is an absence of slow rotators with very short orbital period. These results are consistent with the expected features for the synchronization process in binary systems with evolved components. While the great majority of binary systems with enhanced rotation present a circular or nearly circular orbit, one star represented in Figure 3, HR 407, appears to violate the general rule. This star, in spite of the very short orbital period of 5.4291 days, has a F5III spectral type which may indicate that, at this evolutionary stage, the extent of its convective envelope and the effectiveness of convection in transporting energy flux are not yet well developed, indicating that tidal effects are not yet enough to produce a circular or nearly circular orbit. On the basis of this reasoning the deviating behavior of HR 407 in the $v \sin i$ –period–eccentricity plane is easily understood. Naturally, enhanced rotation is not a general property among binary systems with circularized orbits. As shown in Figure 3, binary systems with circular or nearly circular orbits present a wide range of $v \sin i$ values, from a few km s^{-1} to about 40 km s^{-1} .

We have also analyzed the behavior of the rotational velocity, $v \sin i$, versus the mass function, $f(m)$, searching for particular features between rotation and stellar mass. Clearly, the mass function per se is not a very useful parameter because of its rather complex dependence on the inclination angle i of the orbital plane with respect to the plane of the sky. The relevance of such analysis rests on the fact that the mass function, $f(m)$, has a direct dependence on the orbital period, P , and eccentricity, e , namely on P and $(1 - e^2)$, respectively. Nevertheless, no significant feature resulted from this analysis.

4. Conclusions

Precise rotational velocities, $v \sin i$, are given for a large sample of 134 single lined binary systems with an evolved component of luminosity class III. For these binary systems the distribution of rotation rates as a function of color index ($B - V$) presents a behavior that seems to parallel the one found for their single counterparts. Namely, there is a sudden decline in rotation around the spectral type G0III, as is the case for single giants. Binary systems located blueward of the spectral type G0III, typically those systems with a color index ($B - V$) lower than about 0.70, present a large spread in the values of rotational velocity, from a few km s^{-1} to at least 40 km s^{-1} . In addition, we have found that along the G and K spectral regions there is a considerable number of moderate to moderately high rotators reflecting, clearly, the effects of synchronization between rotation and orbital motions. These

stars have orbital periods shorter than about 250 days as well as circularized or nearly circularized orbits. For a given spectral type, the process of synchronization increases the observed rotational velocity of the binary systems up to about 15 times the mean rotational velocity of single giants. Except for these synchronized systems, the majority of binary stars later than spectral type G0III is essentially composed of slow rotators, following the same behavior as single giants. A few binary systems present synchronization characteristics and low rotation but probably their $v \sin i$ is suppressed by low inclination of their rotation axis. We have also observed that enhanced rotation is not a general property among binary systems with circularized orbit. Admittedly, in the present study the number of binary systems with F-type component is very scarce and one should be cautious with the proposed rotational discontinuity around the spectral type G0III. In addition the extent of tidal effects along the F spectral region is not yet established. In this context only the determination of rotational velocity and orbital parameters for a larger sample of binary systems with F-type component could confirm such a discontinuity on more solid basis. Finally, we would like to point out that for the large majority of stars discussed in this work the duplicity is established on very solid grounds. However for 58 stars additional measurements of radial velocity are undoubtedly necessary to establish their orbital parameters. Nevertheless, it is important to underline that the discussion of the rotational velocity for binary systems with evolved component carried out in the present work is not hampered by this fact because, in particular, the large majority of stars with no available orbital parameters are slow rotators.

We acknowledge the Geneva Observatory for the important amount of observing time awarded for this work. It is a pleasure for J. R. M. to thank warmly Prof. Michel Mayor for his generous help all along this research and all colleagues at the Geneva Observatory who made the time in Geneva pleasant and productive. We express our thanks to the Referee for his careful reading and constructive comments on the original version of this paper. We are grateful to the CNPq and CAPES Brazilian Councils for continued financial support.

REFERENCES

- [Bassett 1978] Bassett, E. E. 1978, The Observatory, 98, 122
- [Baranne et al. 1979] Baranne, A., Mayor, M., Poncet, J. L. 1979, Vistas in Astron., 23, 279
- [Batten 1989] Batten, A. H., Fletcher, J. M., MacCarthy, D. G. 1989, Publ. Dom. Astrophys. Obs. 17, 1
- [Beavers and Griffin 1979] Beavers, W. I., Griffin, R. G. 1979, PASP, 91, 521

- [Benz and Mayor 1981]Benz, W., Mayor, M. 1981, A&A, 93, 235
- [Benz and Mayor 1984]Benz, W., Mayor, M. 1984, A&A, 138, 183
- [Bertiau 1957]Bertiau, F. C. 1957, ApJ, 125, 696
- [Boffin et al 1993]Boffin, H. M. J., Cerf, N., Paulus, G. 1993, A&A, 271, 125
- [Carquillat et al. 1983]Carquillat, J. –M., Nadal, R., Ginestet, N., Pédoussaut, A. 1983, A&AS, 54, 187
- [Christie 1936]Christie, W. H. 1936, ApJ, 83, 433
- [De Medeiros et al. 1996]De Medeiros, J. R., Da Rocha, C., Mayor, M. 1996, A&A, 314, 499
- [De Medeiro and Mayor 1989]De Medeiros, J. R., Mayor, M. 1989, PASP Conference Series, 9, 404
- [De Medeiros and Mayor 1991]De Medeiros, J. R., Mayor, M. 1991, in Angular Momentum Evolution of Young Stars, eds. S. Catalano and I. R. Stanffer, NATO ASI Series, vol. 340, p. 201
- [De Medeiros and Mayor 1999]De Medeiros, J. R., Mayor, M. 1999, A&AS, 139, 433
- [1999]De Medeiros, J. R., Udry, S. 1999, A&A, 346, 532
- [Duquennoy et al. 1991]Duquennoy, A., Mayor, M., Halbwachs, J. –L. 1991, A&AS, 88, 281
- [Fekel 1993]Fekel, C. F. et al. 1993, AJ, 106, 2370
- [Franklin 1952]Franklin, K. L. 1952, ApJ, 116, 383
- [Frink]Frink, S., Quirrenbach, A. 2001, PASP, 113, 173
- [Giuricin et al. 1984]Giuricin, G., Mardirossian, F., Mezzetti, M. 1984, A&A, 131, 152
- [Gray 1989]Gray, D. F. 1989, ApJ, 347, 1021
- [Griffin 1967]Griffin, R. F. 1967, ApJ, 148, 465
- [Griffin 1978]Griffin, R. F. 1978, The Observatory, 98, 14
- [Griffin 1981a]Griffin, R. F. 1981a, JApA, 2, 115
- [Griffin 1981b]Griffin, R. F. 1981b, The Observatory, 101, 208

- [Griffin 1982a]Griffin, R. F. 1982a, MNRAS, 200, 1161
- [Griffin 1982b]Griffin, R. F. 1982b, The Observatory, 102, 27
- [Griffin 1982c]Griffin, R. F. 1982c, The Observatory, 102, 82
- [Griffin 1983]Griffin, R. F. 1983, The Observatory, 103, 199
- [Griffin 1984a]Griffin, R. F. 1984a, The Observatory, 104, 267
- [Griffin 1984b]Griffin, R. F. 1984b, The Observatory, 104, 6
- [Griffin 1985]Griffin, R. F. 1985, The Observatory, 105, 7
- [Griffin 1986]Griffin, R. F. 1986, The Observatory, 106, 35
- [Griffin 1988]Griffin, R. F. 1988, The Observatory, 108, 155
- [Griffin 1990]Griffin, R. F. 1990, The Observatory, 110, 177
- [Griffin 1991a]Griffin, R. F. 1991a, JApA, 12, 39
- [Griffin 1991b]Griffin, R. F. 1991b, The Observatory, 111, 29
- [Griffin 1991c]Griffin, R. F. 1991c, The Observatory, 111, 108
- [Griffin 1991d]Griffin, R. F. 1991d, The Observatory, 111, 155
- [Griffin 1992]Griffin, R. F. 1992, The Observatory, 112, 219
- [Griffin 1998]Griffin, R. F. 1998, The Observatory, 118, 158
- [Griffin and Eitter 1999]Griffin, R. F., Eitter, J. J. 1999, The Observatory, 119, 131
- [Griffin and Eitter 2000]Griffin, R. F., Eitter, J. J. 2000, The Observatory, 120, 260
- [griffin et al. 1983]Griffin, R. F. et al. 1983, JRASC, 77, 73
- [Griffin et al. 1985]Griffin, R. F. et al. 1985, AJ, 90, 609
- [Griffin et al. 1990]Griffin, R. F., Eitter, J. J., Reimers, D. 1990, JApA, 11, 225
- [griffin et al. 1992]Griffin, R. F. et al. 1992, JApA, 13, 209
- [Griffin and Gunn 1977]Griffin, R. F., Gunn, J. E., 1977, AJ, 82, 176
- [Griffin and Herbig 1981]Griffin, R. F., Herbig, G. H. 1981, MNRAS, 196, 33

- [Hall et al. 1995]Hall, D. S. et al. 1995, AJ, 109, 1277
- [Hatzes]Hatzes, A. P., Cochran, W. D. 1993, ApJ, 413, 339
- [Hoffleit and Jaschek 1982]Hoffleit, D., Jaschek, C. 1982, The Bright Star Catalogue, 4th ed., New Haven: Yale University Observatory
- [Hoffleit et al. 1983]Hoffleit, D., Saladyga, M., Wlasak, P. 1983, A Supplement to the Bright Star Catalogue, Yale University Observatory, New Haven
- [Hut 1980]Hut, P. 1980, A&A, 92, 167
- [Jackson et al. 1957]Jackson, E. S., Shane, W. W., Lynds, B. T. 1957, ApJ, 125, 712
- [Lucke and Mayor 1982]Lucke, P. B., Mayor, M. 1982, A&A, 105, 318
- [Lucy and Sweeney 1971]Lucy, L. B., Sweeney, M. A., 1971, AJ, 76, 544
- [Luyten 1936]Luyten, W. J. 1936, ApJ, 84, 85
- [Mermilliod & 1992]Mermilliod, J. C., Mayor, M. 1992, in: Binaries as Tracers of Stellar Formation, eds. A. Duquennoy and M. Mayor, Cambridge University Press, Cambridge, p. 183
- [Maeder and Meynet 1994]Maeder, A., Meynet, G. 1994, A&A, 287, 803
- [Middelkoop and Zwaan 1981]Middelkoop, F., Zwaan, C. 1981, A&A, 101, 26
- [Morbey 1974]Morbey, C. L., Brosterhus, E. B. 1974, PASP, 86, 455
- [Radford and Griffin 1975]Radford, G. A., Griffin, R. F. 1975, The Observatory, 95, 143
- [Scardia et al. 2000]Scardia, M., et al. 2000, Astron. Nachr., 321, 255
- [Scarfe 1971]Scarfe, C. D. 1971, PASP, 83, 807
- [Scarfe et al 1983]Scarfe, C. D. et al. 1983, MNRAS, 203,103
- [Scarfe and Alers 1975]Scarfe, C. D., Alers, S. 1975, PASP, 87, 285
- [Strassmeier et al. 1993]Strassmeier, K. G., et al. 1989, A&AS, 72, 291
- [Zahn 1966]Zahn, J. –P. 1966, Ann. Astroph., 29, 489
- [Zahn 1977]Zahn, J. –P. 1977, A&A, 57, 383

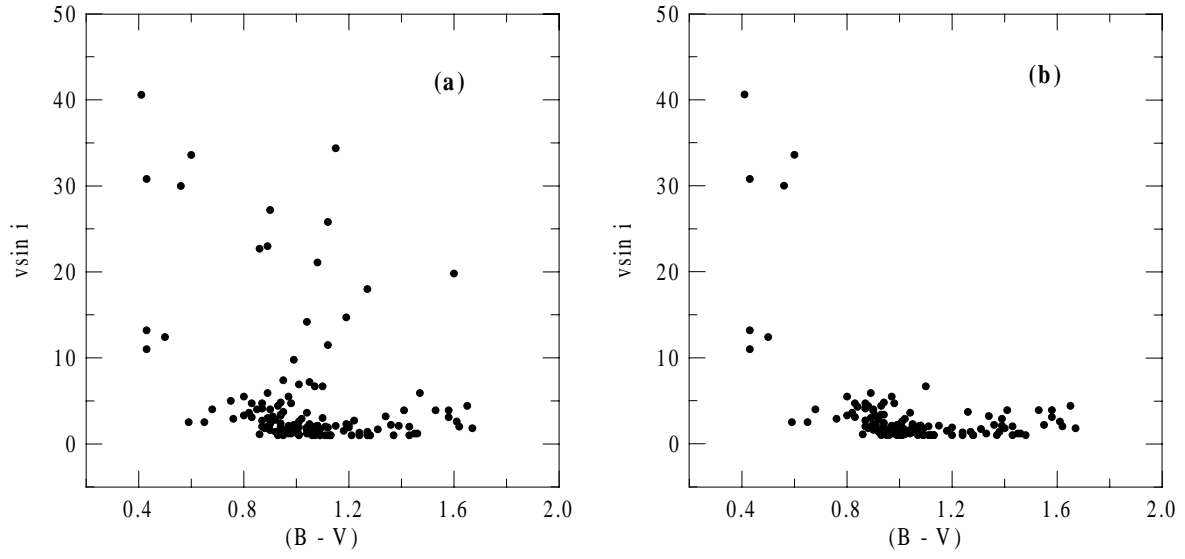


Fig. 2.— The distribution of the rotational velocity $v \sin i$ for binary systems with evolved component. (a) For all the stars listed in Table 3. (b) For systems with G- or K-type component but with orbital period longer than 250 days and all the systems with F-component.

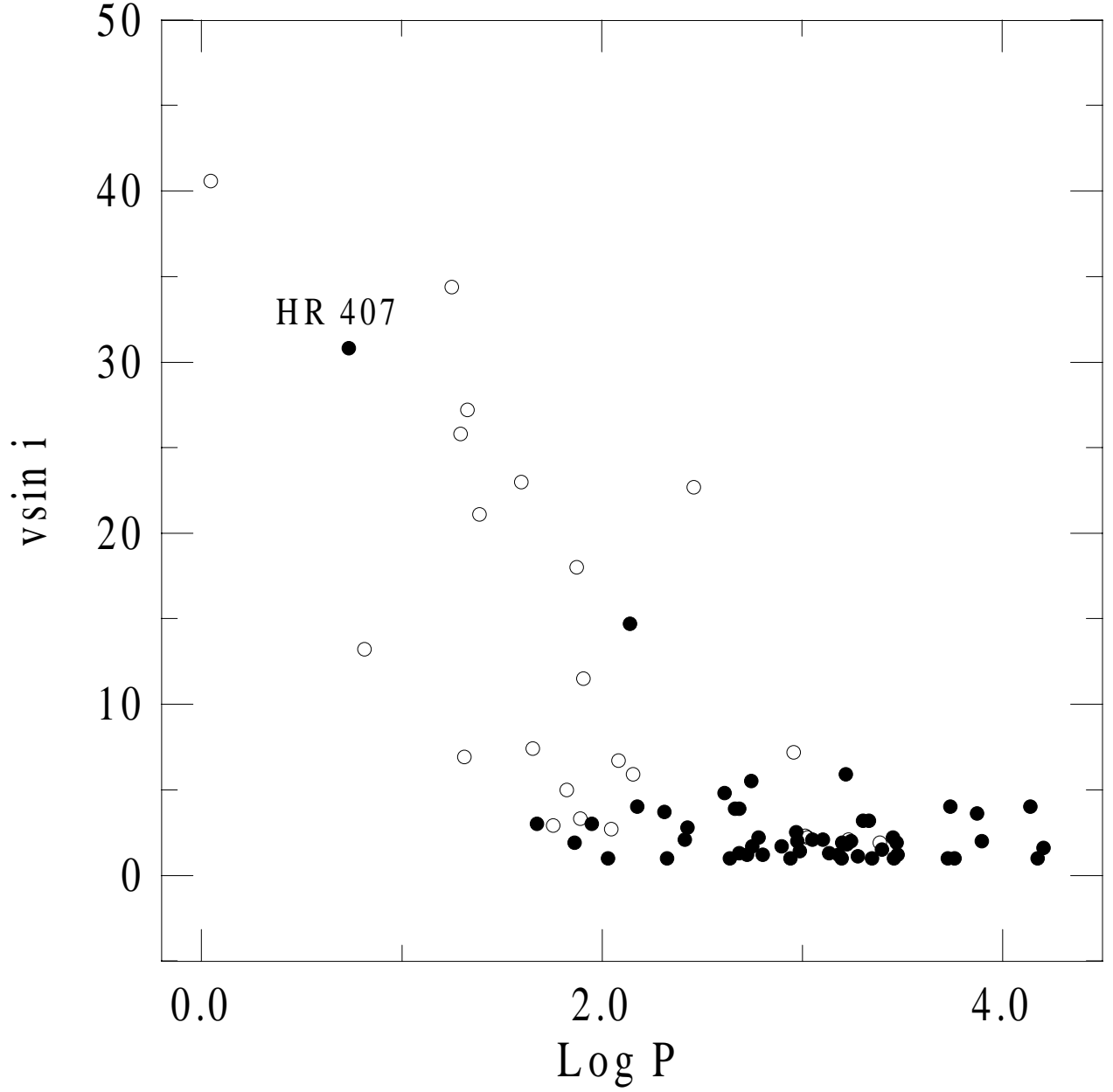


Fig. 3.— The distribution of the rotational velocity $v \sin i$ as a function of the orbital period, for the binary systems listed in Table 3 with available orbital parameters. Binary systems with a circular or nearly circular orbit, ($e \leq 0.10$) are represented by open symbols whereas the systems with eccentric orbits, ($e > 0.10$) are represented by solid symbols. The deviating behavior of the star HR 407 is discussed in the text

Table 2. Comparison between $v \sin i$, in km s^{-1} , obtained by CORAVEL (COR) and Fourier transform technique (Gray).

HR	HD	$v \sin i$ (COR)	$v \sin i$ (Gray)
373	7672	2.9	4.5
1030	21120	5.9	4.8
1373	27697	1.2	2.5
3112	65448	2.5	2.4
4301	95689	1.6	2.6
5161	119458	4.0	4.9
5681	135722	1.2	1.1
6148	148856	4.8	3.4
6239	151627	4.1	4.7
6322	153751	23.0	24.0
7995	198809	4.7	5.9
8359	208010	3.3	4.0
8442	210220	1.8	3.4
8819	218658	5.5	4.7
8923	221115	1.5	3.1

Table 3. Stellar parameters for binary systems with evolved components.

HR	HD	$B-V$	Spectral type	$v \sin i$ kms^{-1}	P days	e	N	σ kms^{-1}	ϵ kms^{-1}	ΔT days	σ/σ_n
3	28	1.04	K1III	1.9	72.93	0.27	...	...	...	...	...
40	895	0.65	G0III	2.5	932.22	0.832	...	...	...	...	...
165	3627	1.28	K3III	1.0	15000	0.34	...	...	...	...	...
216	4526	0.94	G8III	1.7	...	...	2	9.96	7.04	309	19.92
360	7318	1.04	K0III	3.6	7473	0.816	...	...	...	...	...
373	7672	0.90	G5IIIe	2.9	56.8147	0.04	...	...	...	...	...
407	8634	0.43	F5III	30.8	5.4291	0.38	...	...	...	...	...
469	10072	0.89	G8III	2.0	7581	0.368	...	...	...	...	...
503	10588	0.94	G8III–IV	3.3	78.0073	0.02	...	...	...	...	...
549	11559	0.94	K0III	1.8	1672.4	0.18	...	...	...	...	...
645	13530	0.93	G8III:v	1.0	1575.48	0.8815	...	...	...	...	...
731	15596	0.90	G5III–IV	1.6	...	...	2	1.20	0.85	301	2.40
738	15755	1.07	K0III	1.0	...	...	2	13.17	9.31	285	26.34
754	16161	0.87	G8III	2.7	...	...	2	6.73	4.76	302	13.46
765	16246	0.41	F6III	40.6	1.109526	0.062	...	...	...	...	...
831	17484	0.43	F6III–IV	11.0	...	...	2	2.04	1.44	302	4.08
1023	21018	0.86	G5III	22.7	287.201	0.0	...	...	...	...	...
1030	21120	0.89	G6IIIFe–1	5.9	1654.9	0.263	...	...	...	...	...
1198	24240	1.05	K0III	2.3	...	...	2	3.75	2.65	419	7.50
1304	26659	0.87	G8III	4.7	...	...	5	1.58	0.71	2037	3.16
1313	26755	1.09	K1III	1.0	...	...	2	6.72	4.75	267	13.44
1337	27278	0.94	K0III	2.0	...	...	2	2.62	1.85	267	5.24
1360	27497	0.92	G8III–IV	1.4	...	...	4	3.12	1.56	3637	6.24
1373	27697	0.98	K0IIICN0.5	1.2	529.8	0.42	...	...	...	...	...
	28591	0.90	K1III	27.2	21.2886	0.010	...	...	...	...	...
1467	29317	1.07	K0III	6.7	121	0.02	...	...	...	...	...
1514	30138	0.93	G9III	4.4	...	...	2	1.76	1.24	329	3.52
1517	30197	1.21	K4III	1.0	107.503	0.210	...	...	...	...	...
1623	32357	1.12	K0III	11.5	80.90	0.05	...	...	...	...	...
1698	33856	1.19	K3III	2.3	1031.40	0.098	...	...	...	...	...
1726	34334	1.27	K3III	1.0	434.8	0.1	...	...	...	...	...
1908	37171	1.58	K4III	3.9	...	...	2	5.78	4.08	367	11.56
1970	38099	1.47	K4III	5.9	143.03	0.06	...	...	...	...	...
2054	39743	0.99	G8III	9.8	...	...	3	4.87	2.81	1067	9.74
2077	40035	1.00	K0III	1.7	...	...	2	1.97	1.39	288	3.94
2145	41380	1.04	G4III	14.2	...	...	3	6.25	3.61	1079	12.50
2264	43905	0.43	F5III	13.2	6.5013	0.02	...	...	...	...	...
2376	46101	1.60	K0III:	19.8	...	...	2	13.48	9.53	282	26.96
2506	49293	1.11	K0IIIBa0.1	2.0	1760.9	0.40	...	...	...	...	...
2553	50310	1.20	K0III	2.2	1066.0	0.09	...	...	...	...	...
2804	57646	1.61	K5III	2.6	...	...	2	1.20	0.85	219	2.40

Table 3—Continued

HR	HD	$B-V$	Spectral type	$v \sin i$ kms ⁻¹	P days	e	N	σ kms ⁻¹	ϵ kms ⁻¹	ΔT days	σ/σ_n	
3385	72688	0.95	K0III	7.4	45.13	0	...	...	...	...	...
3482	74874	0.68	G5III	4.0	5492	0.61	...	...	...	...	...
3512	75605	0.87	G5III	2.0	...	...	3	1.89	1.09	1440	3.78	
3531	75958	0.86	G6III	1.1	1898.7	0.706	...	...	...	...	...
3567	76629	0.98	G8III	4.7	...	...	3	4.96	2.86	2290	9.92	
3627	78515	0.97	K0III	2.1	1700.76	0.060	...	...	...	...	...
3722	80953	1.46	K2III	1.2	...	...	2	4.43	3.13	265	8.86	
3725	81025	0.75	G2III	5.0	66.717	0.0	...	...	...	...	...
3827	83240	1.05	K1IIIv	2.2	2834	0.322	...	...	...	...	...
3907	85505	0.94	G9III	3.4	...	...	4	3.01	1.50	2309	6.02	
3994	88284	1.01	K0III	1.9	1585.8	0.14	...	...	...	...	...
4100	90537	0.90	G9IIIab	4.0	13833	0.66	...	...	...	...	...
4235	93859	1.12	K2III	1.0	...	...	2	1.09	0.77	419	2.18	
4301	95689	1.07	K0IIIa	1.6	16060	0.35	...	...	...	...	...
4365	97907	1.20	K3III	1.9	2963	0.420	...	...	...	...	...
4427	99913	0.94	K0III	2.4	...	...	2	3.13	2.21	320	6.26	
4430	99967	1.27	K2IIICN-1	18.0	74.861	0.03	...	...	...	...	...
4451	100418	0.60	F9III	33.6	...	...	5	3.72	1.67	1803	7.44	
4593	104438	1.01	K0III	1.1	...	...	2	1.77	1.25	243	3.54	
4640	105981	1.41	K4III	3.9	461	0.17	...	...	...	...	...
4693	107325	1.09	K2III-IV	1.0	5792	0.55	...	...	...	...	...
4793	109519	1.22	K1III	2.7	110.829	0	...	...	...	...	...
4795	109551	1.31	K2III	1.7	561.7	0.262	...	...	...	...	...
4815	110024	0.96	G9III	1.4	972.4	0.590	...	...	...	...	...
4927	113049	0.99	K0III	1.6	...	...	4	2.88	1.44	1838	5.76	
5053	116594	1.06	K0III	1.3	1366.8	0.193	...	...	...	...	...
5161	119458	0.85	G5III	4.0	149.72	0.17	...	...	...	...	...
5201	120539	1.43	K4III	2.0	944	0.41	...	...	...	...	...
5203	120565	1.01	G9III	2.6	...	...	2	1.24	0.88	341	2.48	
5321	124547	1.36	K3III	2.2	605.8	0.137	...	...	...	...	...
5361	125351	1.06	K0III	1.0	212.085	0.574	...	...	...	...	...
5520	130458	0.82	G5III	3.6	...	...	3	2.63	1.52	2555	5.26	
5681	135722	0.95	G8IIICN-1	1.2	...	...	11	2.98	0.90	5213	5.96	
5692	136138	0.97	G8IIIaBa0.3	5.5	...	...	4	5.28	2.64	996	10.56	
5769	138525	0.50	F6III	12.4	...	...	2	6.64	4.70	215	13.28	
5802	139195	0.95	K0III:CN1B	1.0	5324	0.345	...	...	...	...	...
5826	139669	1.58	K5III	3.1	...	...	2	1.28	0.90	708	2.56	
5835	139906	0.83	G8III	3.1	...	...	5	5.43	2.43	2514	10.86	
6005	144889	1.37	K4III	1.0	2230	0.14	...	...	...	...	...
6018	145328	1.01	K0III-IV	1.0	...	...	31	4.49	0.81	6925	8.98	
6046	145849	1.34	K3III	3.2	2150	0.6	6	...	...	...	...
6148	148856	0.94	G7IIIc	4.8	410.575	0.55	...	...	...	...	...

Table 3—Continued

HR	HD	$B-V$	Spectral type	$v \sin i$ kms ⁻¹	P days	e	N	σ kms ⁻¹	ϵ kms ⁻¹	ΔT days	σ/σ_n
6790	166207	1.04	K0III	1.6	...	...	2	1.66	1.17	276	3.32
6791	166208	0.91	G8IIICN-0.3CH	3.2	2017	0.378	...	...	...	...	...
6853	168322	0.99	G9III	1.8	...	...	22	2.76	0.59	5542	5.52
6860	168532	1.53	K3III:Ba0.	3.9	485.45	0.359	...	...	...	...	...
6886	169221	1.07	K1III	2.0	...	...	2	2.82	1.99	339	5.64
7010	172424	0.96	G8III	1.5	...	...	3	1.03	0.59	372	2.06
7024	172831	1.00	K1III	1.3	485.3	0.209	...	...	...	...	...
7125	175306	1.19	G9IIbCN-0.5	14.7	138.420	0.11	...	...	...	...	...
7135	175515	1.04	K0III	1.2	2994	0.24	...	...	...	...	...
7137	175535	0.90	G8III	2.3	...	...	6	3.69	1.51	2579	7.38
7176	176411	1.08	K1IIICN0.5	2.1	1270.6	0.27	...	...	...	...	...
7180	176524	1.15	K0III	2.1	258.48	0.21	...	...	...	...	...
7208	176981	1.67	K2III	1.8	...	...	2	3.91	2.77	295	7.82
7252	178208	1.27	K3III	1.4	...	...	2	10.31	7.29	338	20.62
7333	181391	0.92	G8III-IV	2.8	266.544	0.833	...	...	...	...	...
7413	183611	1.39	K5III	2.1	...	...	2	1.71	1.21	331	3.42
7636	189322	1.13	G8III	1.0	...	...	2	3.30	2.34	312	6.60
7798	194152	1.08	K0III _v	2.1	1124.06	0.759	...	...	...	...	...
7884	196574	0.95	G8III	3.7	205.2	0.138	...	...	...	...	...
7897	196758	1.06	K1III	1.8	...	...	2	2.74	1.94	377	5.48
7901	196787	1.02	G9III	2.9	...	...	12	3.02	0.87	3637	6.04
7939	197752	1.18	K2III	1.5	2506	0.383	...	...	...	...	...
7995	198809	0.83	G7IIICN-1	4.7	...	...	2	3.86	2.73	358	7.72
	199547	1.13	K0III	1.0	2871	0.632	...	...	...	...	...
8035	199870	0.97	K0IIbCN-0.5	1.2	635.1	0.44	...	...	...	...	...
8078	200817	0.99	K0III	2.2	...	...	2	3.98	2.81	366	7.96
8149	202951	1.65	K5III	4.4	...	...	2	5.12	3.62	370	10.24
8359	208110	0.80	G0IIIs	3.3	...	...	6	3.81	1.56	1844	7.62
	209813	1.08	K0III	21.1	24.4284	0.01	...	...	...	...	...
8442	210220	0.88	G6III	1.8	...	...	2	7.03	4.97	381	14.06
8445	210289	1.62	K5III	2.0	...	...	2	1.67	1.18	374	3.34
8575	213389	1.15	K2III	34.4	17.755	0.02	...	...	...	...	...
	217188	1.10	K0III	3.0	47.1162	0.463	...	...	...	...	...
8748	217382	1.43	K4III	1.0	...	...	2	1.04	0.73	334	2.08
8819	218658	0.80	G2III	5.5	556.72	0.297	...	...	...	...	...
8923	221115	0.94	G7III	1.5	...	...	2	2.38	1.68	241	4.76
8961	222107	1.01	G8III-IV	6.9	20.5212	0.04	...	...	...	...	...
8990	222682	1.24	K2III	1.0	...	...	2	1.18	0.83	287	2.36